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EFFECT OF RADIATION ON CERIUM-DOPED SOLAR-CELL COVER GLASS

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EFFECT OF RADIATION ON CERIUM-DOPED SOLAR-CELL COVER GLASS

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SUMMARY

The results of an investigation to determine the feasibility of using an inexpensive, radiation-resistant solar-cell cover glass to replace synthetic fused quartz are reported. Several samples of a frequently used solar-cell cover glass were doped with various amounts of cerium. These samples were irradiated with 1 MeV electrons to a maximum fluence of 5×10^{14} electrons per square centimeter and with 22 MeV protons to a maximum fluence of 10^{13} protons per square centimeter. The effects of the electrons and protons used in this investigation are representative of those of the corpuscular radiation found in space.

Cerium doping of the cover glass improves its radiation resistance. The optimum level of cerium doping appears to be between 1 and 2 percent by weight.

INTRODUCTION

Transparent materials are used to cover solar cells for thermal control and for shielding in a radiation environment. These cover materials must not discolor in a radiation environment. Synthetic fused quartz is the most frequently used material because of its radiation resistance (see ref. 1). Fused-quartz covers are somewhat expensive to produce because they have to be cut to size and ground and polished to the desired thickness (usually between 0.076 and 0.76 mm) and surface quality. For thicknesses less than 0.254 mm, the breakage rate of fused quartz during panel fabrication is high. Annealed sapphire, which is even more radiation resistant than fused quartz, has also been used as solar-cell cover material; however, sapphire is a very expensive material.

The other frequently used cover material is Corning #0211 glass (Micro-Sheet). This glass has a thermal coefficient of linear expansion that more closely matches the silicon solar-cell material than does fused quartz. Micro-Sheet is drawn to thickness and fire polished during manufacture. Consequently, only cutting to size and coating with blue reflective and antireflective coatings, commonly used on cell covers, are required as postproduction operations. The finished product is not as fragile as fused quartz, and the breakage rate is lower. The cost of a finished solar-cell cover of

Micro-Sheet is much less than that of a finished fused-quartz cover; however, Micro-Sheet is not as radiation resistant (see ref. 1).

The purpose of this investigation was to determine the feasibility of using Micro-Sheet doped with cerium as a radiation-resistant solar-cell cover glass. The use of Micro-Sheet instead of fused quartz would substantially reduce the cost of many solar-cell power systems. It is known that cerium, when used as a doping element in glass, can inhibit radiation-induced discoloration. (See refs. 1, 2, 3, 4, and 5.)

EXPERIMENTAL PROCEDURE

Samples containing various amounts of cerium were tested. Laboratory procedures required that the samples be ground and polished instead of drawn and fire polished as with production lots. The samples were doped with 1-, 3-, and 5-percent cerium oxide by weight, and the control samples were undoped. Each sample was $25.4 \times 12.7 \times 3.18$ mm in size. The samples were much thicker than solar-cell covers, but the absorption effects due to cerium doping were more easily observed. The thickness was more than sufficient to stop the 1 MeV electron and 22 MeV proton radiation employed in the experiment.

The sample parameters measured included the spectral transmission and the wide-band transmission. The spectral transmission was measured with a Cary Recording Spectrophotometer, Model 14. The wide-band transmission was measured with an N on P silicon solar cell and a xenon-arc solar simulator. The solar-cell response (0.4 to $1.2 \mu\text{m}$) determined the bandwidth and spectral weighting. (See ref. 6.) These parameters were measured before irradiation and after each exposure of each sample to radiation.

The samples were irradiated with 22 MeV protons at the Oak Ridge 86-inch cyclotron. One sample at a time was irradiated. Four samples from each of the four lots were exposed. Two samples from each lot were exposed at a flux of approximately 10^9 protons per square centimeter per second ($\text{p}/\text{cm}^2\text{-sec}$) to a fluence of 8.7×10^{11} p/cm^2 , and the remaining two samples were exposed to a fluence of 10^{13} p/cm^2 . These fluences were sufficient to produce measurable damage. The samples were separated in this manner because all parametric tests were performed at the Langley Research Center, and data from samples at no fewer than two exposures were desired. The irradiation was in air with the samples near room temperature.

The electron irradiation was performed with the 1.0 MeV cascade-rectifier electron accelerator at the Langley Research Center. All samples were irradiated simultaneously with a swept beam. The irradiation was done in vacuum, and the sample temperatures were less than 311°K . Parametric measurements were made on all samples before irradiation and after exposure to fluences of 10^{13} to 5×10^{14} electrons per square centimeter (e/cm^2) at fluxes of 10^{10} $\text{e}/\text{cm}^2\text{-sec}$ for the lowest fluence and 10^{11} $\text{e}/\text{cm}^2\text{-sec}$ for the highest fluence.

The effects of the 1 MeV electrons and 22 MeV protons used in this experiment are representative of those of the corpuscular radiation found in the near-earth orbital environment.

RESULTS AND DISCUSSION

When Micro-Sheet is doped with cerium, it is affected spectrally as shown in figure 1. The ultraviolet absorption is increased, and a definite absorption band develops at $0.575 \mu\text{m}$ as the level of the doping element is increased. The visual effect is a yellowish coloration. To reduce this coloration, the amount of doping element should be held to the minimum required for optimum radiation resistance. The spectral response of a typical solar cell is between 0.4 and $1.2 \mu\text{m}$. The total effect of cerium doping of the cover glass is shown in figure 2, where the normalized wide-band transmission represents the wide-band transmission of doped glass relative to that of undoped glass. It should be emphasized that the samples tested are 4 to 40 times thicker than most solar-cell covers. Consequently, the transmission losses shown in figure 2 would be much less for optimized covers.

Proton Irradiation Tests

The effects of 22 MeV protons on the spectral transmission of cerium-doped Micro-Sheet are shown in figure 3. Figure 3(a) shows that undoped Micro-Sheet is very susceptible to radiation damage. Spectral-transmission changes appear visually as a brownish discoloration in the glass. Figures 3(a) to 3(d) indicate substantial improvements in the radiation resistance of the glass as cerium is added.

Figure 4 shows the effects of proton irradiation on the wide-band transmission of the glass with various amounts of cerium doping. The curve for undoped glass confirms the radiation sensitivity indicated in figure 3(a). This curve also illustrates the nonlinear degradation of transmission as a function of fluence with most of the damage occurring at low fluences. The curve for 1-percent cerium-doped glass illustrates the improvement in proton-radiation resistance resulting from the addition of cerium. The remaining two curves indicate a further improvement in radiation resistance as the amount of cerium doping is increased. Figure 5 shows the effect of proton irradiation on the wide-band transmission as a function of the level of cerium doping. It appears that the optimum level of cerium doping is between 1 and 2 percent for the exposure levels discussed.

Electron Irradiation Tests

The effects of 1 MeV electrons on the spectral transmission of cerium-doped Micro-Sheet are shown in figure 6. The effects due to electron irradiation are similar to the effects due to proton irradiation. Figure 7 shows the effects of the electron irradiation

on the wide-band transmission of doped and undoped glass. The curve for undoped glass confirms the radiation sensitivity indicated in figure 6(a); it also illustrates the nonlinear degradation of transmission as a function of fluence with most damage occurring at low fluences. The curve for 1-percent cerium illustrates the improvement in electron-radiation resistance resulting from the addition of cerium. Figure 8 shows the effects of irradiation on the wide-band transmission of glass as a function of the level of cerium doping. As in figure 5, it appears that the optimum level of cerium doping is between 1 and 2 percent. The discoloration associated with electron irradiation is shown in figure 9. Proton-induced discoloration is similar.

During the electron-irradiation tests, electron-discharge patterns, fissures in the glass, developed in all samples at all fluences. Figure 9 illustrates the discharge effect in undoped glass (see arrows). Sample GOX 1 (manufacture's sample designation) was unirradiated, sample GOX 7 was exposed to 9×10^{13} e/cm², and sample GOX 5 was exposed to 5×10^{14} e/cm². The results of these tests and previous experiments (refs. 1, 4, 7, and 8) suggest that several factors affect the probability of occurrence of the electron-discharge patterns. Factors which appear to reduce this probability are low dielectric constant, low dissipation factor, method of fabrication, low irradiation rate, and samples thin enough so that the irradiating particles are not absorbed. There has been no occurrence of electron discharges in previous ground or flight experiments using thin, commercially produced Micro-Sheet solar-cell covers. Hence, it is not expected that such a problem would develop as a result of adding cerium.

CONCLUSIONS

The experiment on the effects of radiation on cerium-doped Corning #0211 glass (Micro-Sheet) has shown the following:

1. Substantial degradation in the transmission properties of undoped glass is caused by 1 MeV electrons at fluences of 10^{13} electrons per square centimeter and greater and by 22 MeV protons at fluences of 8.7×10^{11} protons per square centimeter and greater. These effects are representative of those of the corpuscular radiation found in space.
2. The induced degradation of the glass is a nonlinear function of the total fluence of the radiation. Most of the damage occurs at low fluences for undoped glass.
3. Micro-Sheet doped with 1 percent or more of cerium shows an improvement in resistance to 1 MeV electron and 22 MeV proton radiation. The optimum amount of doping element appears to be between 1 and 2 percent by weight.
4. Irradiation with electrons caused electron discharges in all samples tested. The discharges, which result in fissures in the glass, are not expected to develop in optimized solar-cell covers. The covers will be thin enough so that the irradiating particles are not completely absorbed.

5. Based on the above conclusions, it appears feasible to use cerium-doped Micro-Sheet as an inexpensive, radiation-resistant solar-cell cover.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 4, 1970.

REFERENCES

1. Haynes, Gilbert A.; and Miller, William E.: Effects of 1.2 and 0.30 MeV Electrons on the Optical Transmission Properties of Several Transparent Materials. NASA TN D-2620, 1965.
2. Soga, Naohiro; and Tashiro, Megumi: Role of Cerium Ions in Preventing the γ -Ray Induced Coloration of Glass. J. Ceram. Assoc. Japan, vol. 70, no. 5, 1962, pp. 143-147.
3. Kircher, John F.; and Bowman, Richard E., eds.: Effects of Radiation on Materials and Components. Reinhold Pub. Corp., c.1964.
4. Kreidl, N. J.; and Hensler, J. R.: Gamma Radiation Insensitive Optical Glasses. J. Opt. Soc. Amer., vol. 47, no. 1, Jan. 1957, pp. 73-75.
5. Kreidl, N. J.; and Hensler, J. R.: Formation of Color Centers in Glasses Exposed to Gamma Radiation. J. Amer. Ceram. Soc., vol. 38, no. 12, Dec. 1955, pp. 423-432.
6. Haynes, Gilbert A.; and Ellis, Walter E.: Effects of 22 MeV Proton and 2.4 MeV Electron Radiation on Boron- and Aluminum-Doped Silicon Solar Cells. NASA TN D-4407, 1968.
7. Gross, Bernhard: Irradiation Effects in Borosilicate Glass. Phys. Rev., Second ser., vol. 107, no. 2, July 15, 1957, pp. 368-373.
8. Rosebury, Fred: Handbook of Electron Tube and Vacuum Techniques. Addison-Wesley Pub. Co., Inc., c.1965.

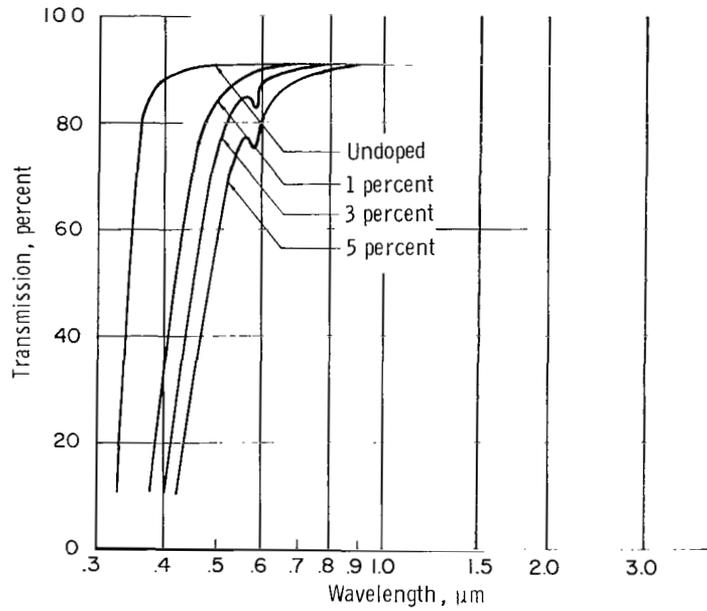


Figure 1.- Effect of cerium doping on the spectral transmission of Micro-Sheet.

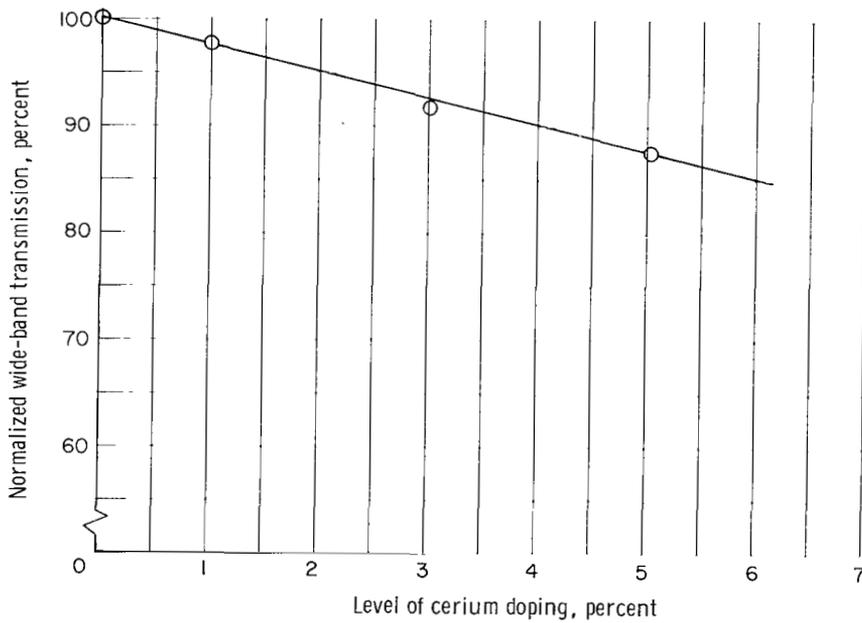
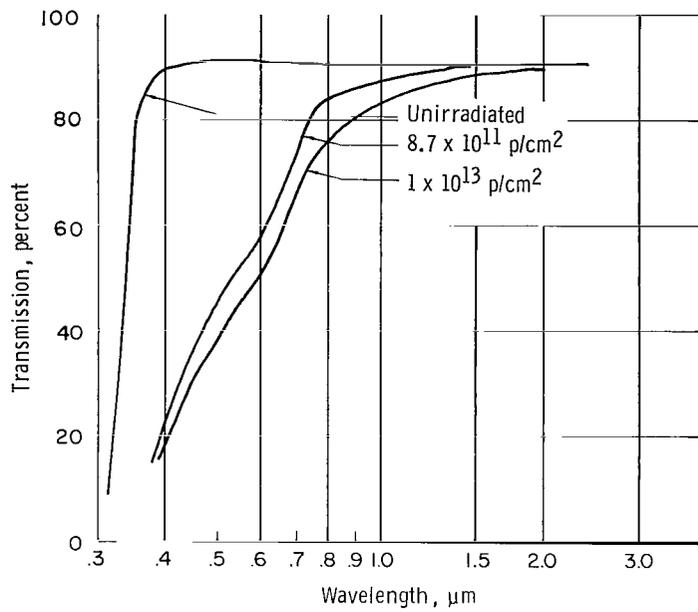
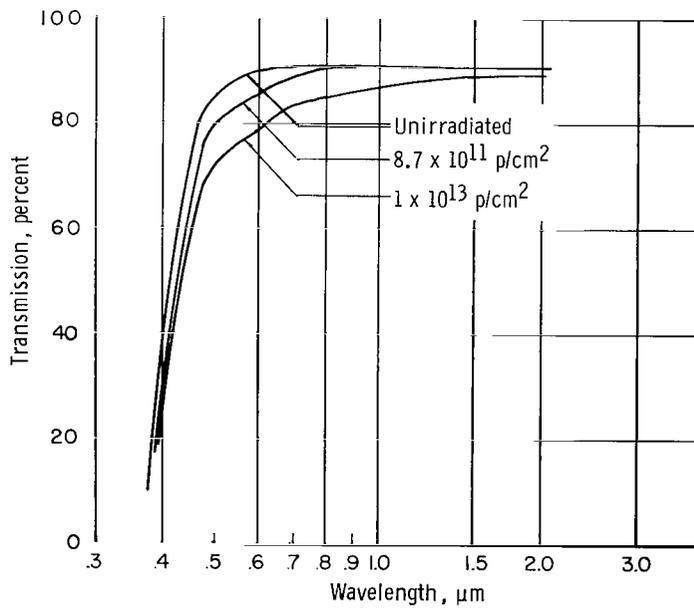


Figure 2.- Effect of cerium doping on the wide-band transmission of Micro-Sheet.

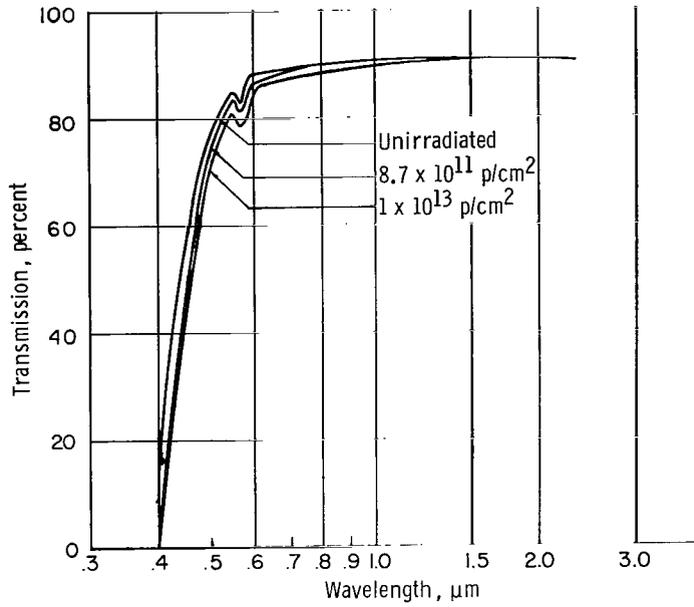


(a) Undoped.

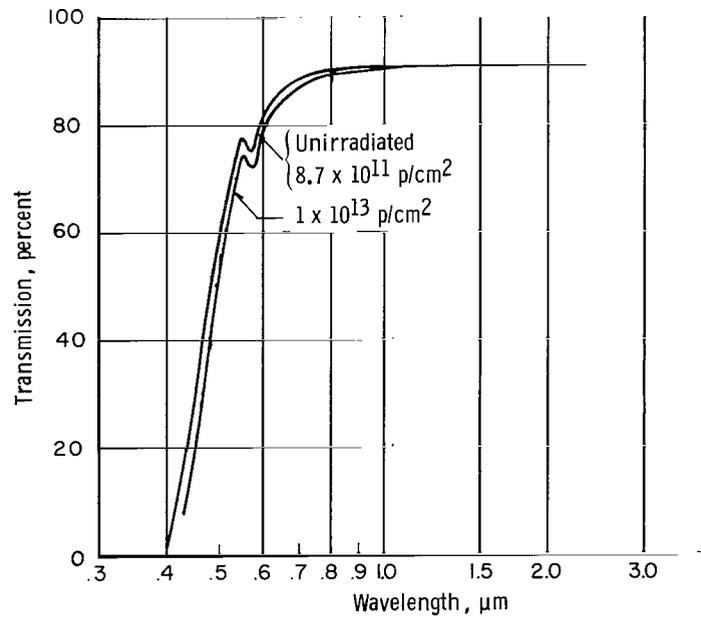


(b) 1-percent cerium doped.

Figure 3.- Effect of 22 MeV proton irradiation on the spectral transmission of Micro-Sheet.



(c) 3-percent cerium doped.



(d) 5-percent cerium doped.

Figure 3.- Concluded.

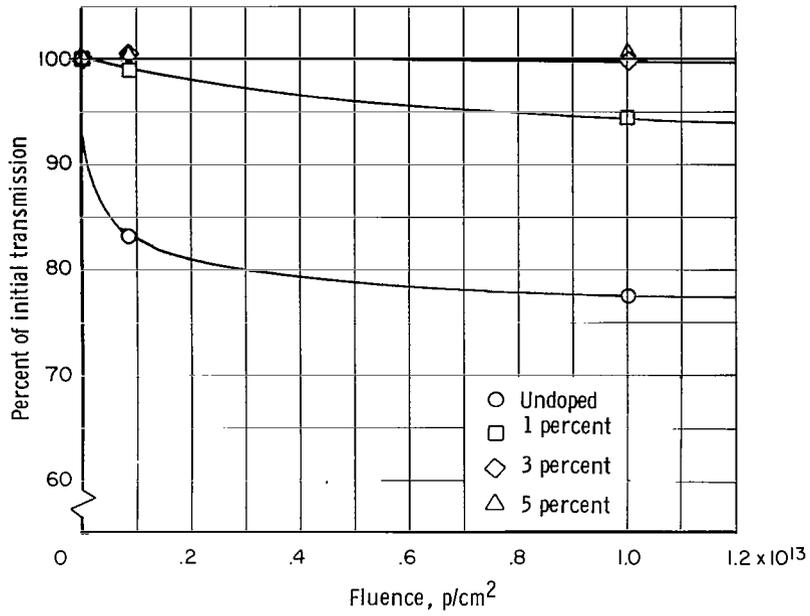


Figure 4.- Effect of 22 MeV proton irradiation on the wide-band transmission of cerium-doped Micro-Sheet.

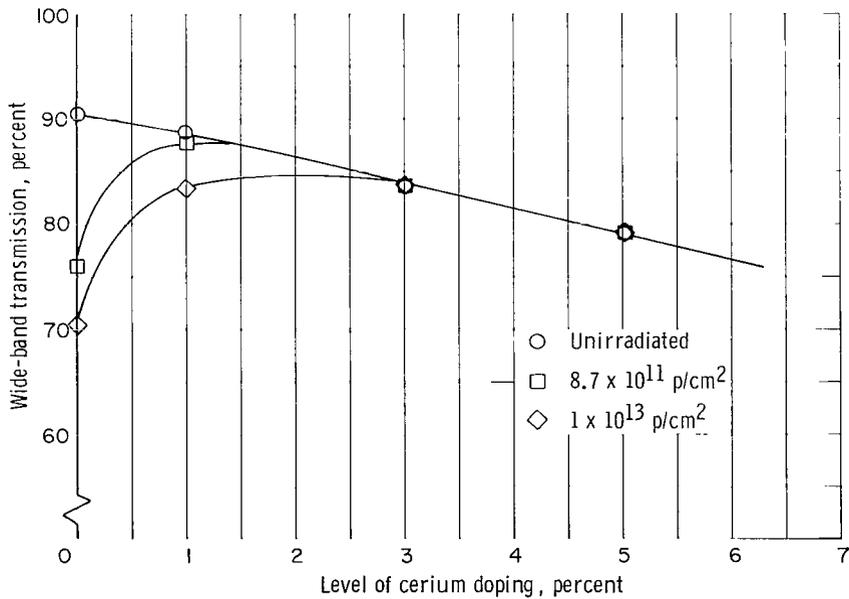
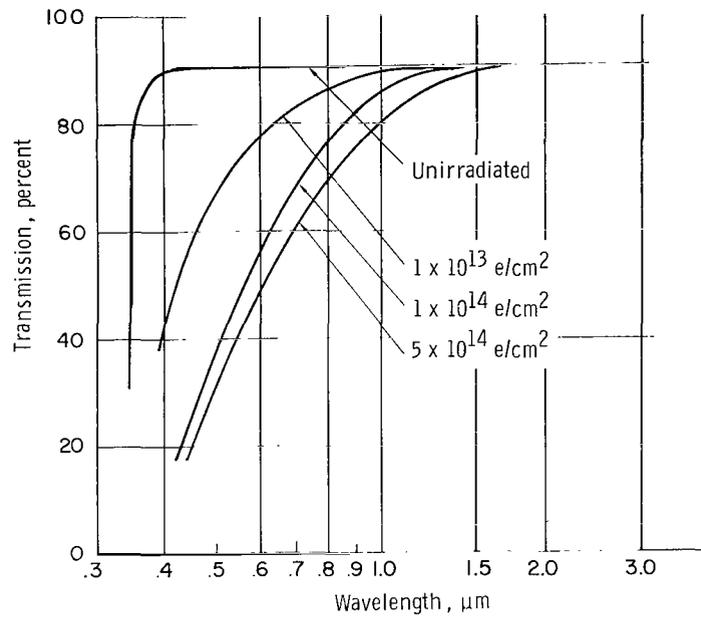
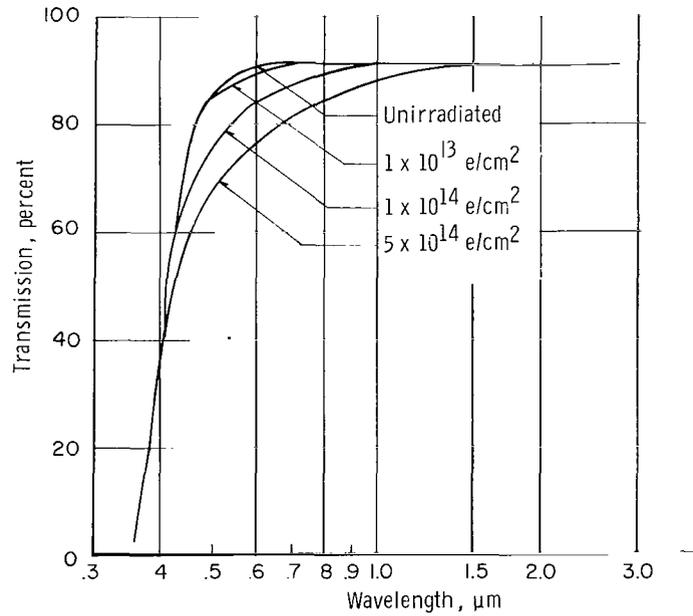


Figure 5.- Effect of cerium on the wide-band transmission of proton-irradiated Micro-Sheet.

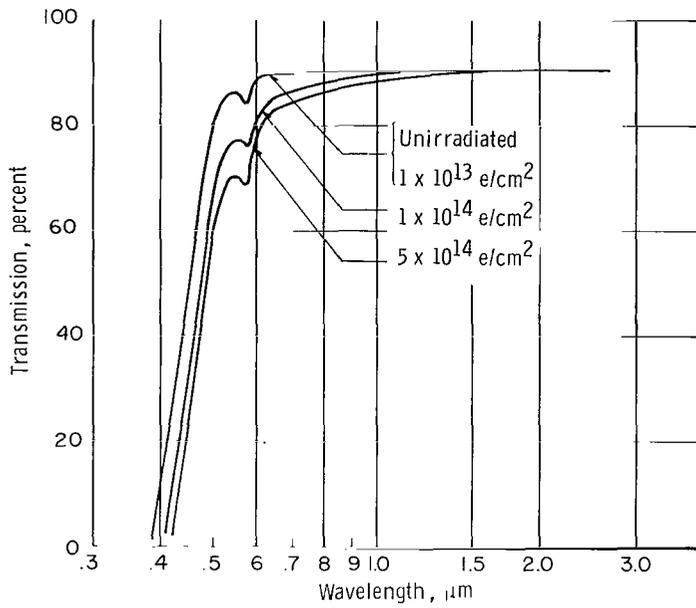


(a) Undoped.

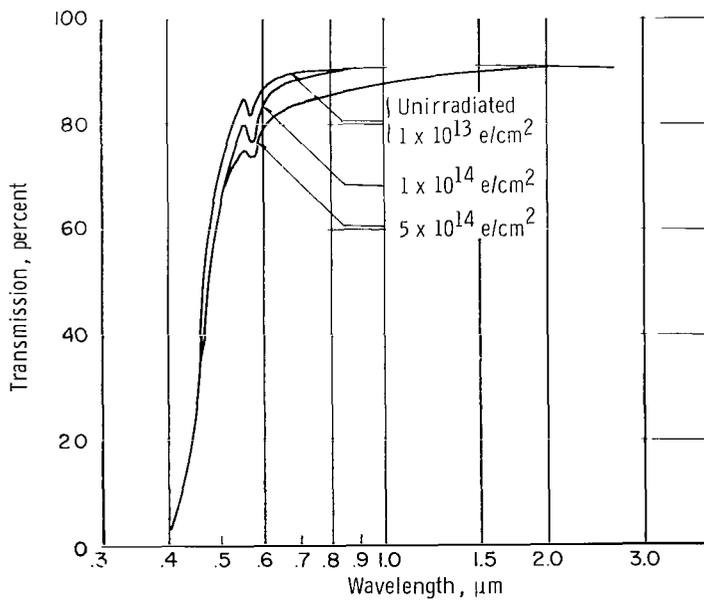


(b) 1-percent cerium doped.

Figure 6.- Effect of 1 MeV electron irradiation on the spectral transmission of Micro-Sheet.



(c) 3-percent cerium doped.



(d) 5-percent cerium doped.

Figure 6.- Concluded.

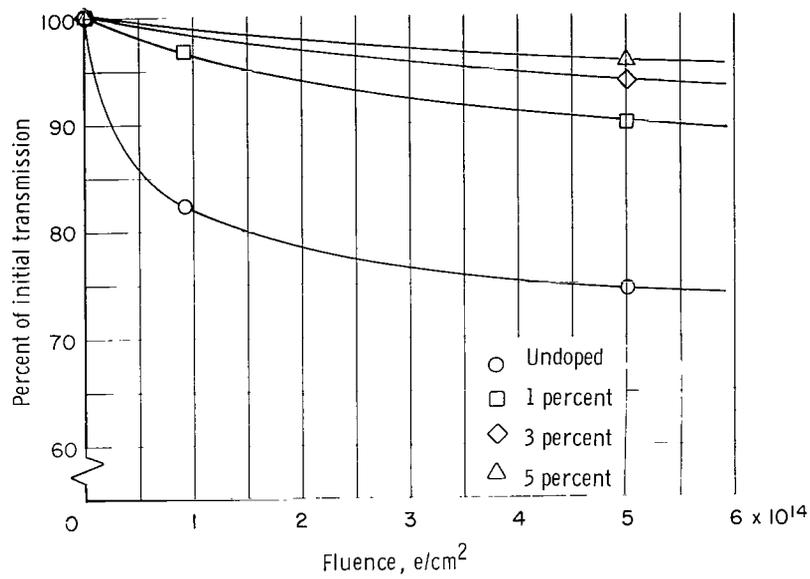


Figure 7.- Effect of 1 MeV electron irradiation on the wide-band transmission of cerium-doped Micro-Sheet.

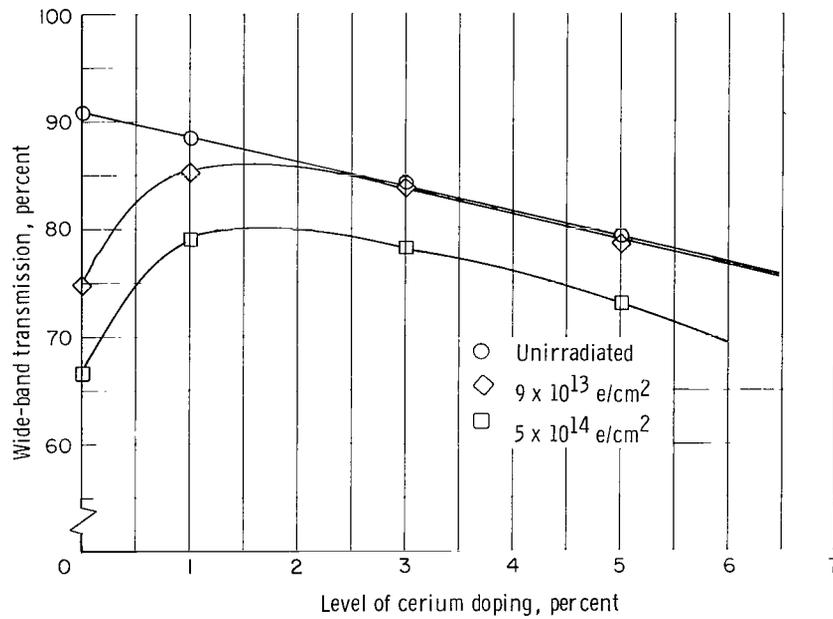


Figure 8.- Effect of cerium on the wide-band transmission of electron-irradiated Micro-Sheet.

Unirradiated

$9 \times 10^{13} \text{ e/cm}^2$

$5 \times 10^{14} \text{ e/cm}^2$

GOX /

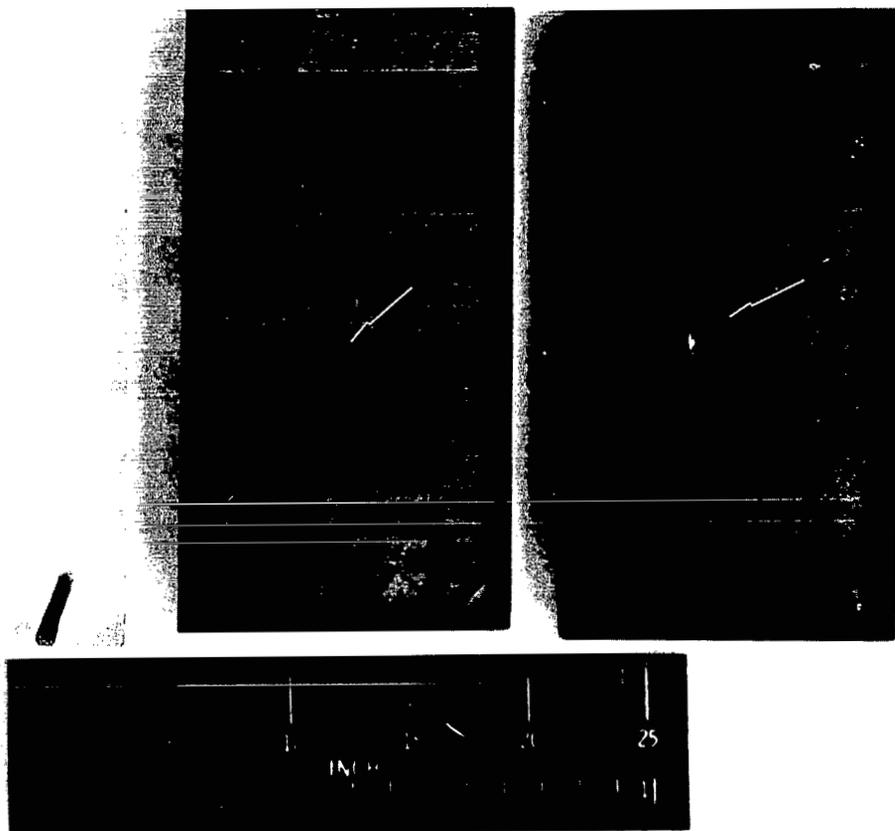


Figure 9.- The discoloration and electron-discharge patterns of Micro-Sheet resulting from electron irradiation. L-68-6750

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